

Towards a seamless cloud fraction scheme for Unified Physics

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Seamless Modelling Workshop

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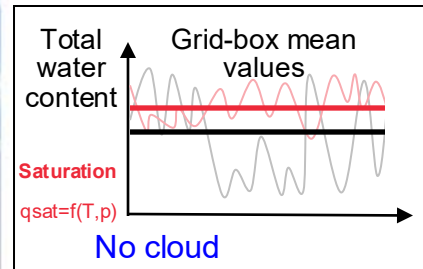
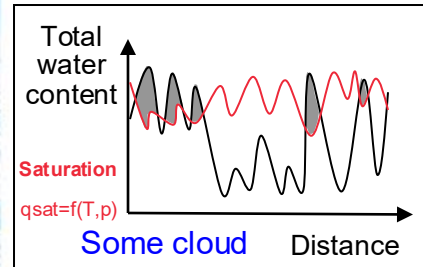
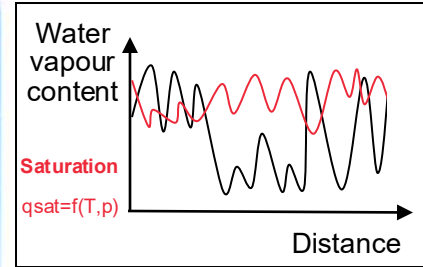
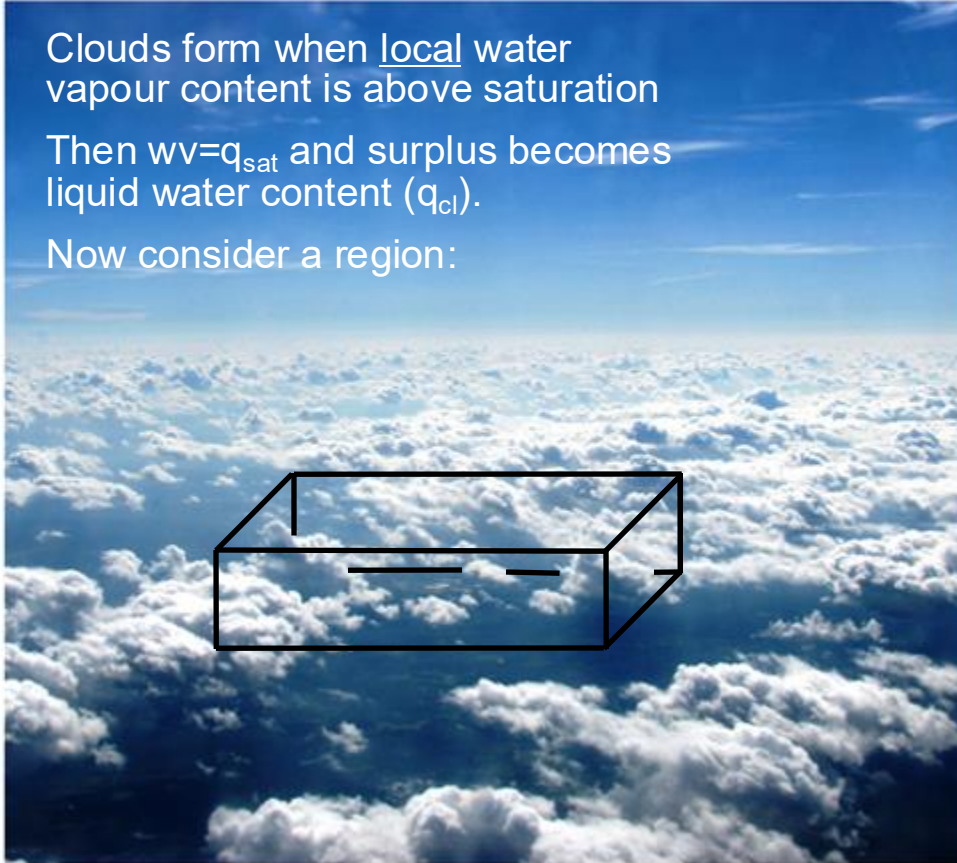
Cloud Fraction Schemes

Cloud formation

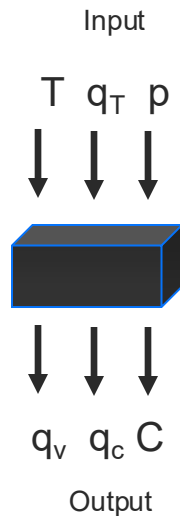
Clouds form when local water vapour content is above saturation

Then $wv = q_{sat}$ and surplus becomes liquid water content (q_{cl}).

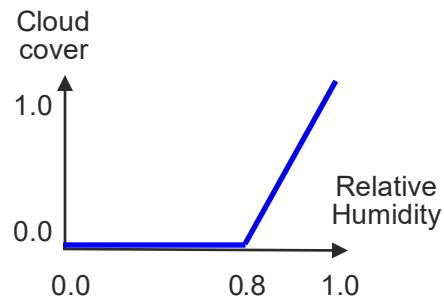
Now consider a region:



A Simple Cloud Scheme



A very simple cloud fraction scheme.



Diagnostic scheme in Unified Model has more complexity, but ultimately for a given atmospheric state (T, q, p) there is only one possible value of cloud cover and liquid water content.

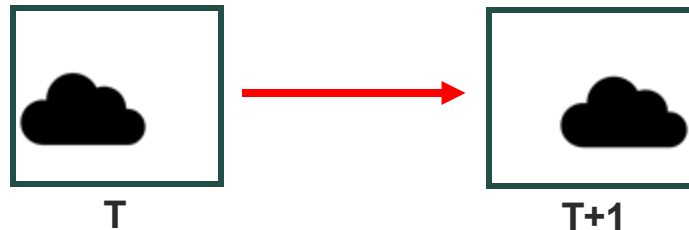
Prognostic vs diagnostic approaches

Diagnostic: Infers cloud water content and cloud fraction from the large-scale state at each timestep. There is **no** memory of what the cloud properties were in any prior timestep.

Prognostic: Specifies a time dependent equation to calculate increments to the cloud water content and cloud fraction from all processes that change temperature and/or specific humidity.

$$\frac{\partial \overline{q_{cl}}}{\partial t} = \frac{\partial \overline{q_{cl}}}{\partial t} |_{advection} + \frac{\partial \overline{q_{cl}}}{\partial t} |_{convection} + \frac{\partial \overline{q_{cl}}}{\partial t} |_{boundary\ layer} + \frac{\partial \overline{q_{cl}}}{\partial t} |_{precipitation} + \dots$$

Clouds are advected through the model and there **is** memory of properties at previous timesteps.



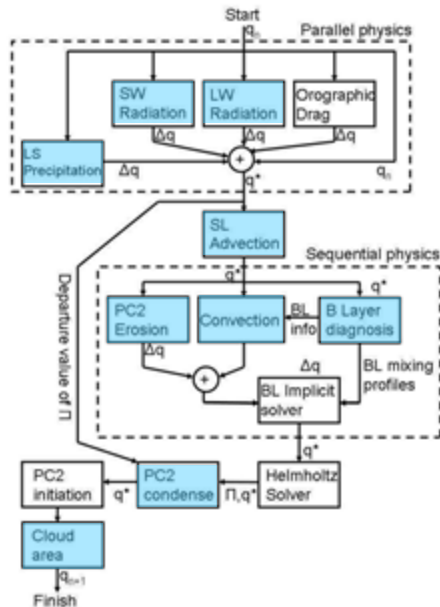
Cloud Macrophysics Schemes

1990

Smith - diagnostic
No 'memory' of cloud fraction, only focusses on current state

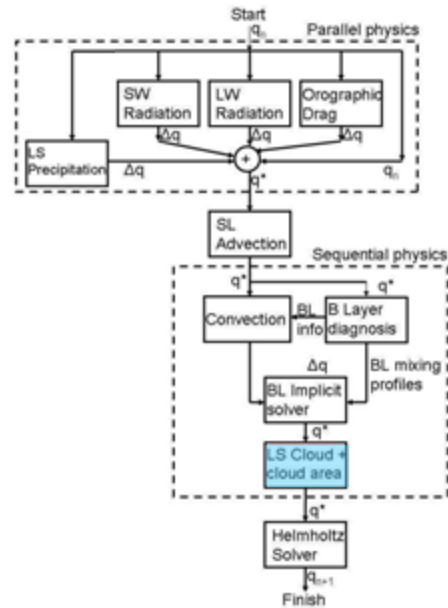
2002

PC2 - prognostic
Has 'memory' of cloud fraction as it considers evolution over time



2020

Bi-Modal – diagnostic
Like Smith scheme but accounts for two modes of variability.



now

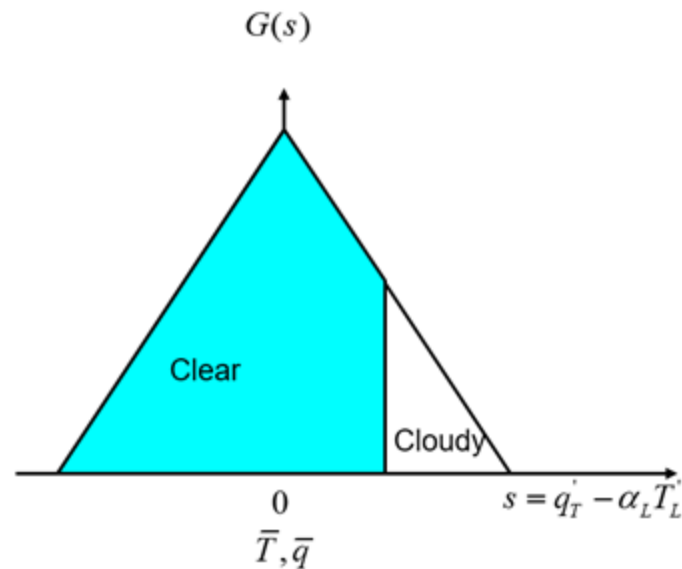
Hybrid
PC2 for ice (prognostic)
Bi-Modal for liquid (diagnostic)

PC2+
PC2 for ice (prognostic)
PC2 for ice with Bi-Modal initiation for liquid (prognostic)

Descriptions of Cloud Fraction Schemes

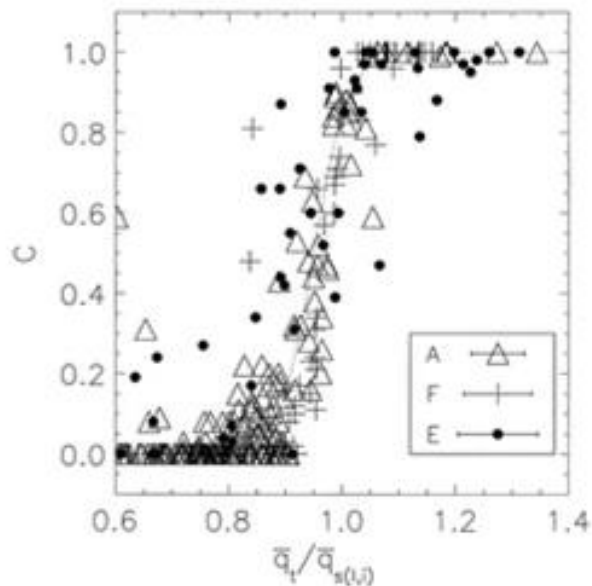
Smith Scheme

- Original UM
- Diagnostic: Assumes supersaturation is instant (OK for liquid, not for ice) – no memory
- Assumes triangular subgrid saturation PDF - fixed width,
- linked to profile of critical relative humidity
- Problem is specifying the width of the PDF
- This is obtained from the variability of q and T in surrounding grid-boxes
- Fixed triangular shape is a problem – there should be some skewness



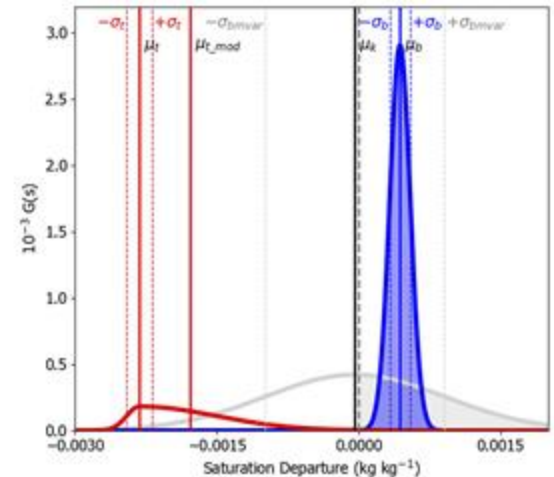
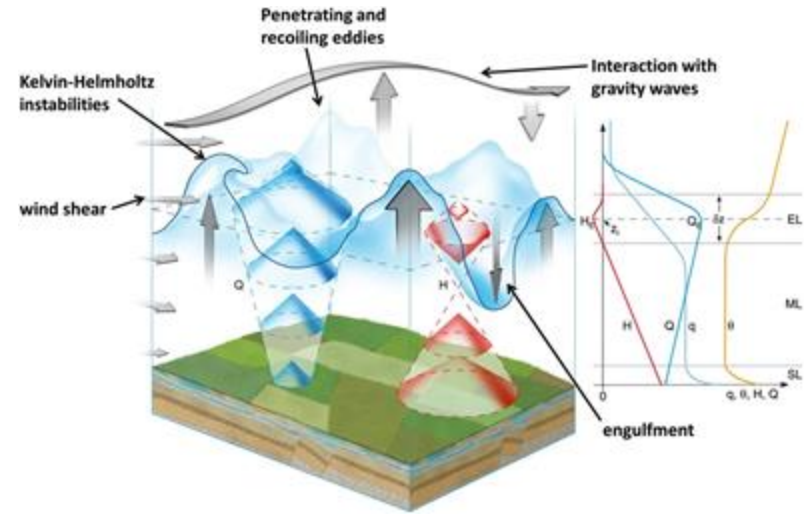
Smith + Empirical Adjustment to Observations

- **observations** suggest that at RH=100% the mean cloud cover is not $C=0.5$, but higher, more like $C=0.65$ or $C=0.7$
- This implies that the PDF of fluctuations is not symmetric after all.
- Hence desire to move away from Smith scheme with its uni-modal symmetric triangular PDF.
- Empirically Adjusted Cloud Fraction (EACF) to observations using: Wood & Field (JAS2000)



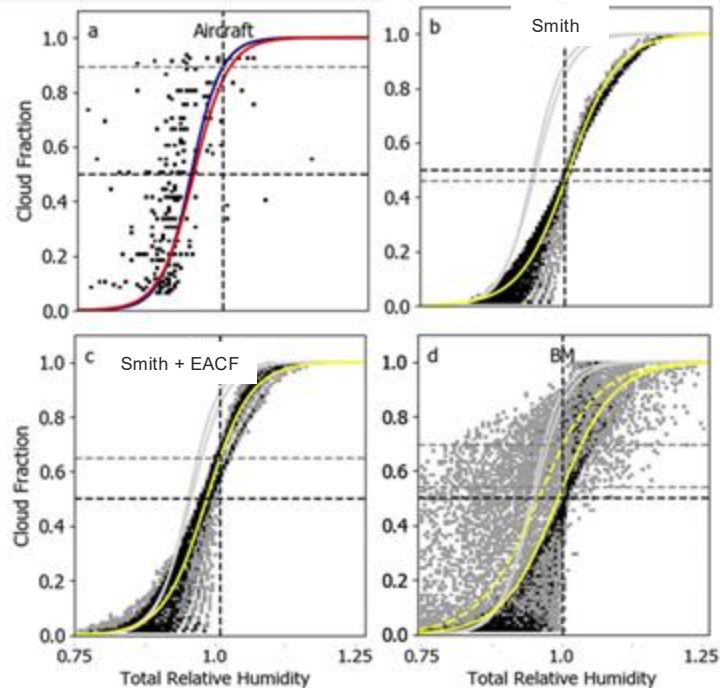
Bi-modal

- Allows for skewed humidity distributions
- Mixing in of air in entrainment zone
- More physically based
- Improved CF forecasts with need for empirical adjustment to observations
- Not perfect!



Bimodal CF Comparisons

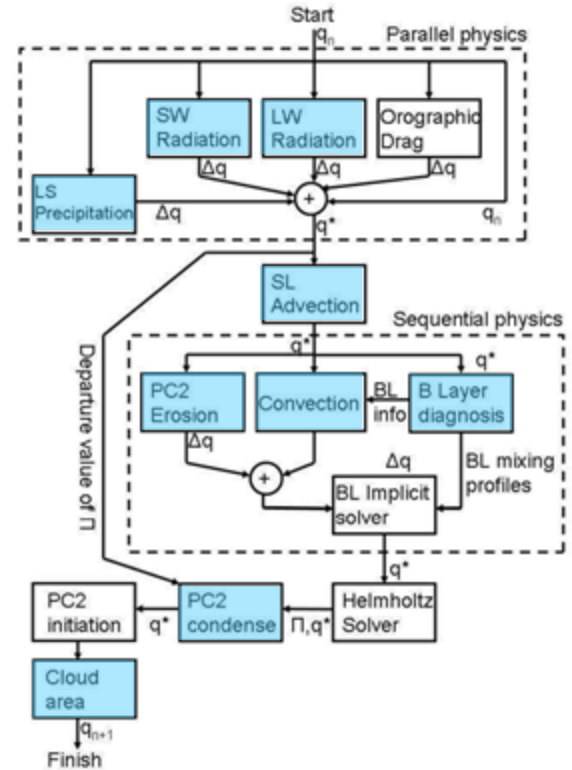
		Cloud fraction at RH=100%	
Observed	90 %		
Smith	47 %		Original UM
Smith EACF	65 %		RA2M
BM	54 %		Better distribution of CF, liquid
BM – EZ	69 %		Entrainment zone



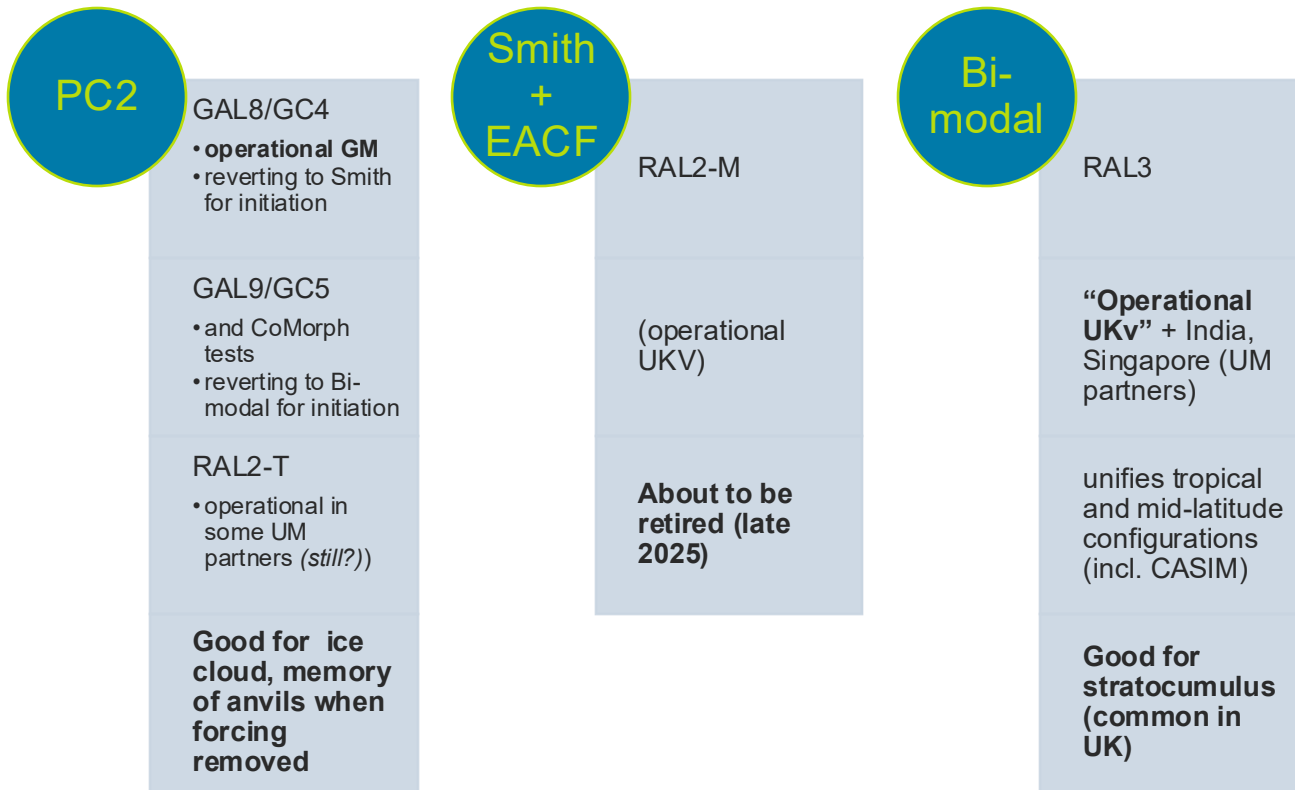
PC2 (Wilson 2008)

- Suppose we have some cloud...
- Some processes will create more
 - Convection, long-wave cooling
- Others will try to destroy it
 - Precipitation, short-wave heating
- As long as we know the PDF of the source and sink terms, we don't actually need to know the PDF of the original cloud
- Mean, variance and skewness all vary in a way consistent with the forcing

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial t} \int_{-Q_c}^{\infty} G(s) ds = G(-Q_c) \frac{\partial Q_c}{\partial t} + \int_{-Q_c}^{\infty} \frac{\partial G(s)}{\partial t} ds$$



Cloud Schemes: What is used where



Unified Physics

Convection

6A
Separate schemes for deep, shallow and mid-level convection

CoMorph
Single parcel ascent / descent code for all plumes

Microphysics

Wilson & Ballard
Single moment

```

    graph TD
      V[VAPOUR] -- "Evaporation" --> R[RAIN]
      R -- "Fall in" --> V
      R -- "Fall out" --> V
      V -- "Condensation" --> L[LIQUID]
      L -- "Evaporation" --> V
      L -- "Bergeron Process" --> I[ICE]
      I -- "Nucleation" --> L
      I -- "Deposition/Sublimation" --> L
      I -- "Melting" --> R
      R -- "Capture" --> I
      I -- "Fall in" --> V
      I -- "Fall out" --> V
      L -- "Freezing" --> I
      I -- "Autoconversion/Accretion" --> V
  
```

CASIM*
Can have multiple moments

```

    graph TD
      WV[Water vapour, qv] -- "Evaporation" --> CW[Cloud water, qc, nc]
      CW -- "Condensation" --> WV
      CW -- "Freezing" --> CI[Cloud ice, qi, ni]
      CI -- "Deposition" --> CW
      CI -- "Sublimation" --> WV
      WV -- "Nucleation" --> CI
      CI -- "Melting" --> CW
      CW -- "Autoconversion" --> R[Rain, qr, nr]
      R -- "Collection" --> CW
      R -- "Fall out" --> WV
      CI -- "Autoconversion" --> S[Snow, qs, ns]
      S -- "Collection" --> CI
      S -- "Fall out" --> WV
      S -- "Melting" --> G[Graupel, qg, ng]
      G -- "Collection" --> S
      G -- "Fall out" --> WV
  
```

Large-Scale Cloud

Smith
Diagnostic

Assumes triangular subgrid saturation-departure probability density function with a fixed width, linked to profile of critical relative humidity

PC2
Prognostic

Calculates increments to liquid and ice cloud fraction and condensate amounts that get advected by the resolved wind

Bi-Modal
Diagnostic

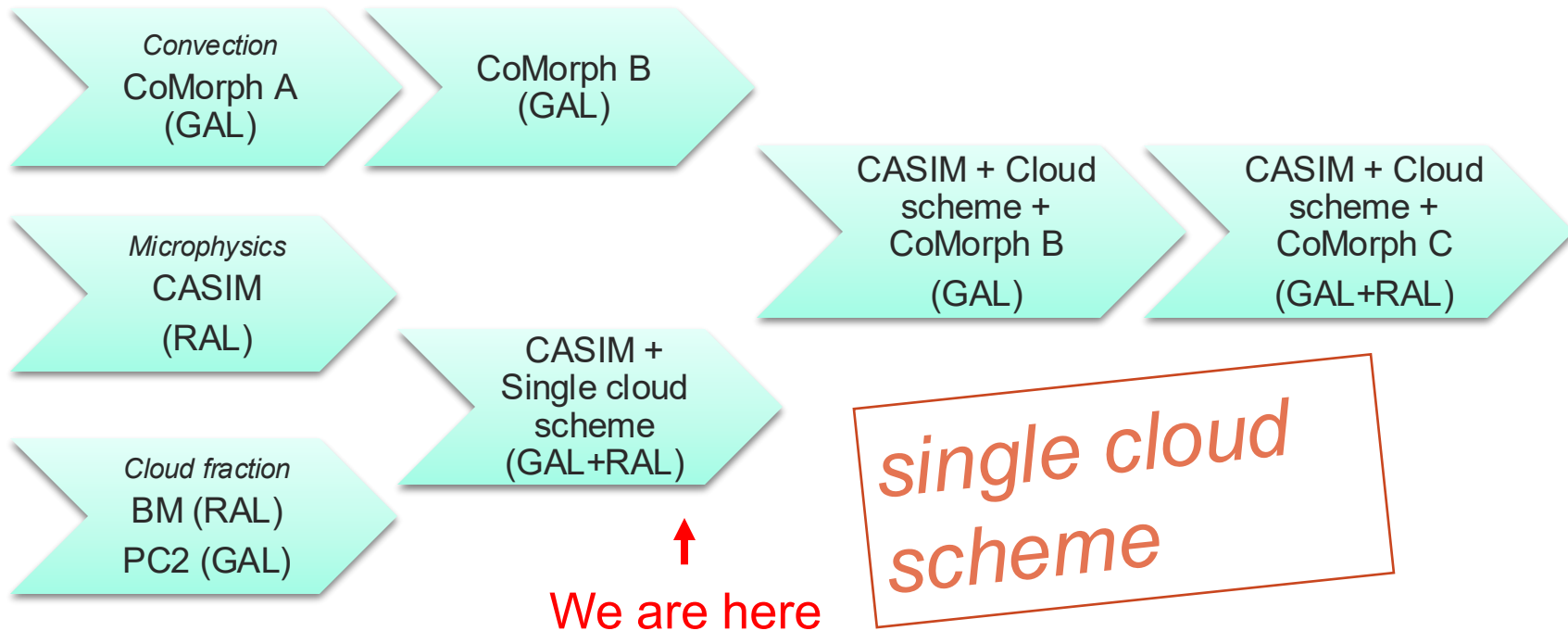
Like Smith scheme but accounts for coexistence of two modes of variability within a grid box near entrainment zones

A hybrid scheme
Prognostic/diagnostic

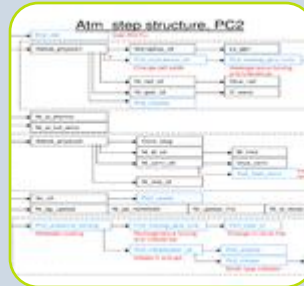
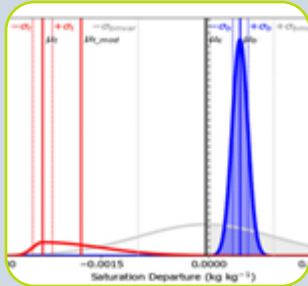
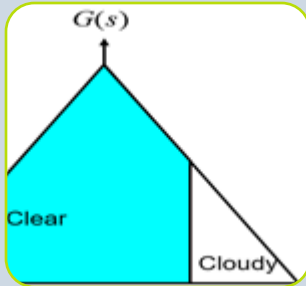
PC2 for ice, Bi-modal for liquid



Order of work



Large Cloud Scheme: Cloud Fraction



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Smith Scheme

Original UM

- **Diagnostics**

- Assumes triangular subgrid saturation PDF - fixed width,
- linked to profile of critical relative humidity
- [Smith \(QJ1990\)](#)
- Empirical adjustment to obs using: [Wood & Field \(JAS2000\)](#)

Bi-modal

Operational
Regional

- **Diagnostics**

- Like Smith scheme
- but accounts for coexistence of two modes of variability within a grid box near entrainment zones
- [van Weverberg \(MWR 2021\)](#)

PC2

Operational Global

- **Prognostic**

- Calculates increments (from BL, conv, etc)
- to liquid and ice cloud fraction and condensate amounts
- Species advected by the resolved wind
- Bimodal used for liquid initiation
- [Wilson \(QJ2008\)](#)

PC2+

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- **Prognostic**

- PC2 for ice,
- PC2 for liquid with Bi-modal initiation
- Many improvements + fixes
- Improved interactions with BL
- Designed to interface to CoMorph and CASIM

Hybrid

Unified Physics
Candidate

- **Prognostic** PC2 for ice,

- **Diagnostics** bimodal for liquid,
- Interfaced to CASIM

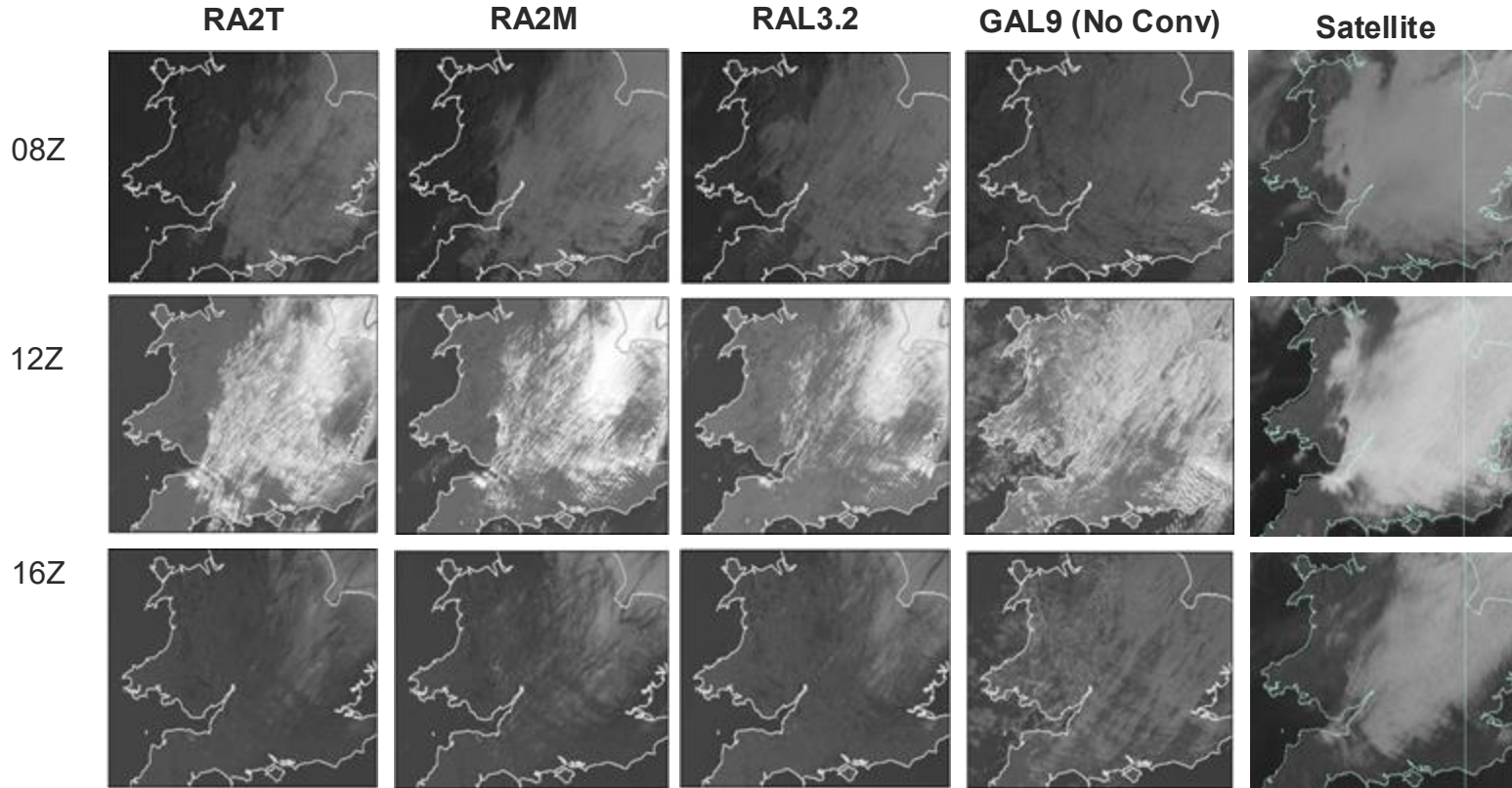
Cloud Scheme Investigation

- Previous studies have shown **no clear ‘winner’ for cloud fraction scheme** yet, since both prognostic and diagnostic approaches show disadvantages
- e.g. PC2 has been shown to be bad at simulating UK stratocumulus, and Bi-Modal performs poorly at climate scales due to a lack of memory (e.g. cirrus anvils)
- We’ve developed a framework for testing candidate cloud fraction schemes using **high resolution (300m)** runs
- This grid spacing was chosen as most deep convection is resolved so **no convection scheme is needed**
- Tests of **shallow cumulus** and **stratocumulus** in the **WesCon* domain** were run with several science configurations

Model Setup

- Ran **high resolution** Regional Nesting Suite (UM **vn13.0**)
- **South UK domain** (50.5°N – 53.5°N, 5.5°W – 1.5°E)
- Simulation length = **30 hours** (but first 6 hours will be model spin-up) starting at 12Z the day before
- Global resolution = n1280, first nested region resolution = 1.5km, second nested region resolution = **300m**
- Ran the following configurations:

Config.	Cloud Scheme	Microphysics Scheme
GAL9 (No Conv)**	PC2 (prognostic)	Wilson & Ballard (1M)
RAL3.2	Bi-Modal (diagnostic)	CASIM (2M)
RA2M	Smith (diagnostic)	Wilson & Ballard (1M)
RA2T	PC2 (prognostic)	Wilson & Ballard (1M)



Next Steps

To simulate partial stratocumulus cover due to detrainment of cloud by parameterised convection at coarse resolution, we probably need a prognostic cloud scheme, since cloud-cover in dry grid-mean environments mainly depends on past history of convective detrainment.

If UP is going to generalise across scales, then it likely needs a prognostic cloud-scheme (even though it probably isn't needed at km-scale).

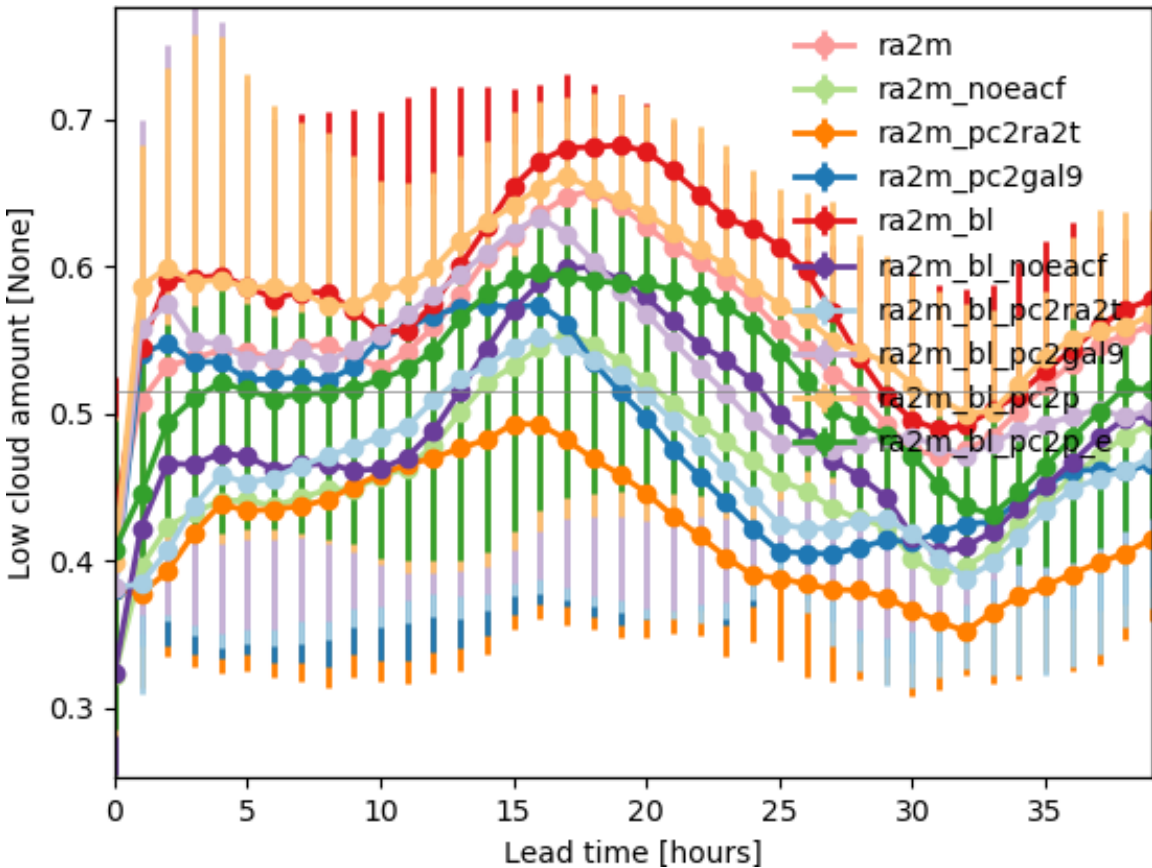
But existing regional model configurations use diagnostic cloud-scheme (bimodal in RAL3) and seem to depend on it for model performance (previous UK NWP tests using PC2 looked pretty bad...)

Options:

- a) Try to extend existing RA diagnostic bimodal cloud-scheme to include a prognostic variable fed by convective detrainment?
- b) Try and implement the existing PC2 prognostic cloud-scheme and improve it so it works better at km-scale?

Next: attempting option (b) – explore why PC2 performs badly in UK regional NWP and try to fix it!

Results



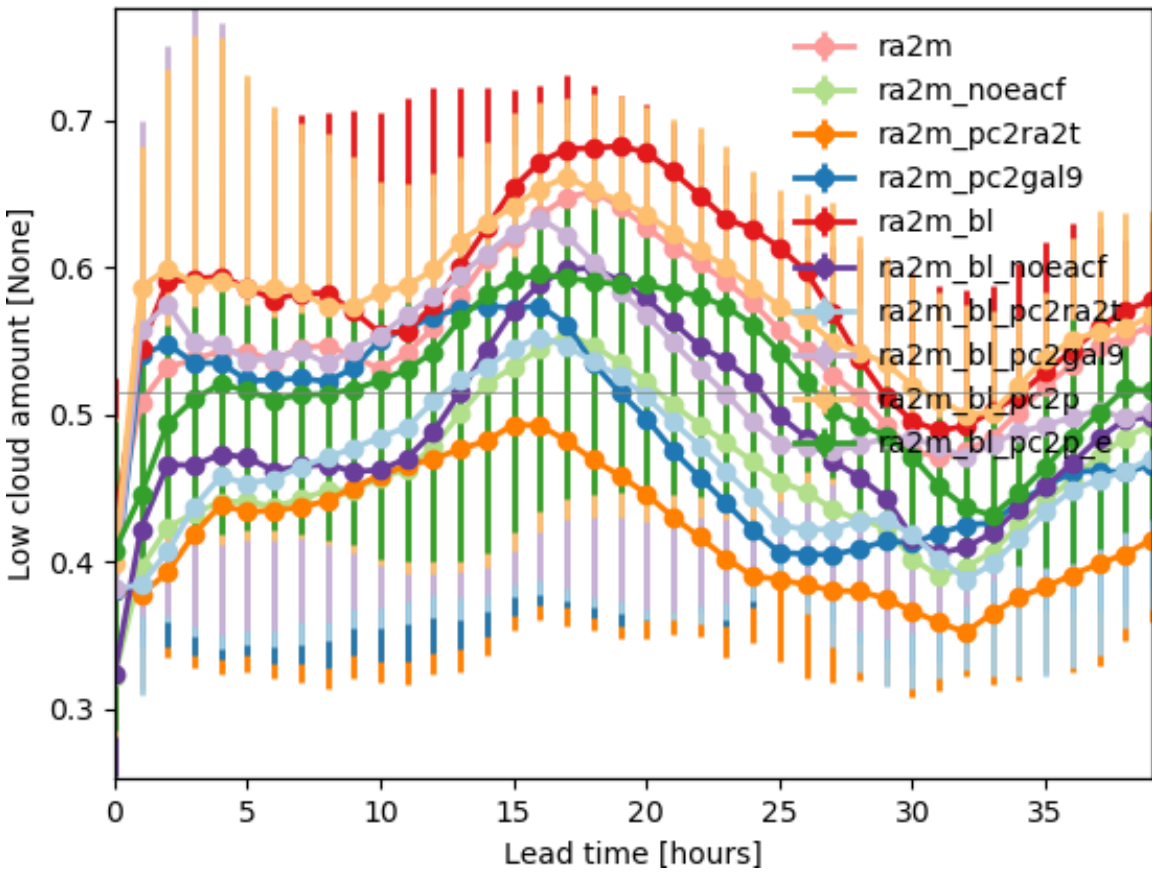
Low cloud amount averaged over UKV model-domain and 8 different forecast dates

RA2M (Smith)

RA2M (PC2)

Switching from **Smith** (fixed RHcrit) to the **PC2 setup used in RA2T** (initiation of condensation still uses Smith, but with TKE-based RHcrit) reproduces historically-seen detrimental large reduction in low-cloud cover.

Results



Low cloud amount averaged over UKV model-domain and 8 different forecast dates

RA2M (Smith)

RA2M (Smith) EACF off

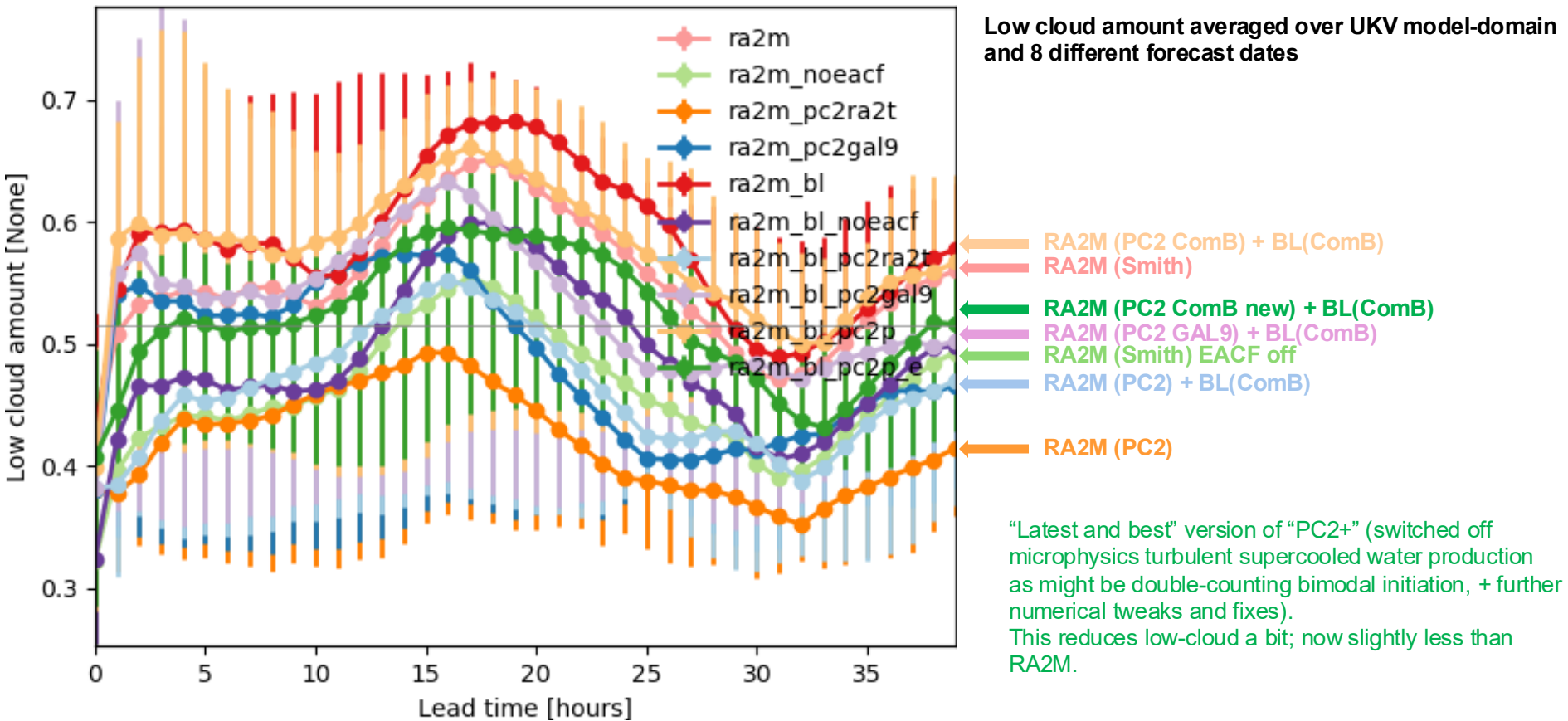
RA2M (PC2) + BL(ComB)

RA2M (PC2)

How can we increase low-cloud again?

1) Numerical improvements to turbulent mixing in stratocumulus (part of the CoMorph B package). This gets us back to where we were with Smith (excluding EACF).

Results



Results so far

- Can recreated porr PC2 performance in Sc
- Can get PC2 close to Smith with new fixes
- Ironed out many config discrepancies Global:regional
 - E.g. Turbulence components
- Identified more discrepancies to work on
 - E.g. treatment of erosion of clouds

Next Steps

- Two candidate cloud fraction schemes are being prepared: PC2+ and Hybrid
- PC2 for Ice – prognostic,
- Further high-resolution tests (without parameterised convection)
- Explore performance across regimes – UK stratocu + showers + frontal, Darwin tropical convection, Arctic cold-air-outbreak, New Mexico continental convection

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PC2+

Unified Physics
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- **Prognostic**
- PC2 for ice,
- PC2 for liquid with Bi-modal initiation
- Many improvements + fixes
- Improved interactions with BL
- Designed to interface to CoMorph and CASIM

Hybrid

Unified Physics
Candidate

- **Prognostic** PC2 for ice,
- **Diagnostic** bimodal for liquid,
- Interfaced to CASIM
- Input of mode of variability from convection (CoMorph)

Problem: PC2 has never been *entirely* implemented in the regional model!

Alas! Alack!

Several bugs specifically exposed by switching on PC2 in LAMs ☹️ Links to tickets describing the bugs found so-far and attempts to fix them:

Purple
Orange

= fixed in the tests shown here.
= fix not yet code-up.

#785 (Set prognostic cloud-fractions in LAM LBCs when using the PC2 cloud-scheme) – Regional Model Evaluation and Development

#7927 (Set PC2 area cloud fraction consistently in LAM-domain edge points) – Unified Model



Prognostic cloud-fractions inherit previous junk from LAM domain edge halo points when winds blow into the domain.

#7948 (Consistently increment prognostic cloud when using horizontal turbulent mixing with PC2) – Unified Model



300m runs occasionally crash due to area-cloud-fraction (used by radiation) not set at LAM boundary points.

#7949 (Implement PC2 erosion when using PC2 with CASIM and no convection scheme) – Unified Model



PC2 cloud-fraction update from horizontal turbulent mixing has never been implemented => fields become inconsistent.



PC2 erosion not yet implemented with CASIM => partial cloud-fractions wrongly persist forever!